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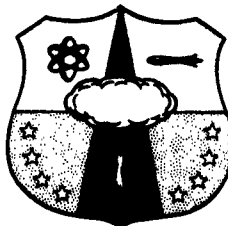
THE PRODUCTION OF
RANDOMLY DISTORTED AND DETERIORATED PATTERNS

by

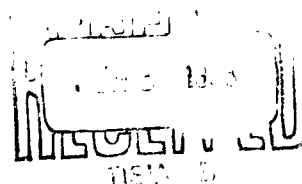
Richard E. Manelis
Lt USAF

April 1963

TECHNICAL DOCUMENTARY REPORT NUMBER AFSWC-TDR-63-44



Test Directorate
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FOREWORD

The purpose of this study is to provide a series of computer subroutines which will enable the user to take a set of patterns and expand them into a larger distorted set. The input to these subroutines will consist of a binary representation of a perfect character (or characters). The output will be a binary representation of the same character(s) with a predetermined amount and type of distortion and/or displacement.

A set of programs of this type may be useful for the testing of character recognition systems. It is the object of these recognition systems to adequately identify an input character which may be distorted in only one or in several ways. To facilitate the testing of such a recognition scheme it is desirable to have a large variety of samples of characters. These characters may be of many different fonts with varying degrees of serifs. For each of these categories, samples should be available with varying amounts and types of distortion or deterioration. An adequate analysis along these lines would necessitate the use of hundreds of samples. For a full alphabet consisting of letters (both lower case and capitals), numbers, punctuation, and special symbols, it would be virtually impossible to make all of these up individually.

The subroutines discussed in this report provide a means whereby the desired samples might be obtained from one original of each type. While the characters generated by these routines (used separately or in various combinations) may not correspond to a particular type of distortion or deterioration, it is believed that an adequate simulation of actual conditions will be realized.

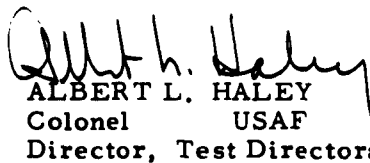
ABSTRACT

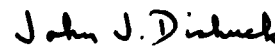
This study develops a set of computer subroutines which attempt to simulate various degrees of distortion and deterioration on an input character. A complete set of the letters of the Cyrillic alphabet, numerals, and some punctuation were quantized and punched to be used as ideal input characters to transforming subroutines.

These transforming subroutines permit the generation of large sample sets of characters containing controlled amounts of various types of distortion. Use of the routines will produce a set of test characters in which the pattern size, percentage distortion (or amount of shift), and number of output samples desired are parameters. The output of any of the programs developed can be used as the input to a character recognition routine. It is the object of this study to produce a variety of source pattern representations of the same pattern. The user can thus develop his own series of tests to determine the identification criteria invariance of a recognition scheme. The use of these programs is demonstrated in conjunction with a recognition routine.

PUBLICATION REVIEW

This report has been reviewed and is approved.


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1. INTRODUCTION

Character generation, as defined for this study, is the production of distorted patterns, both random and controlled, with a predetermined amount (percentage) of deterioration or change. This distortion can manifest itself in many ways: variations in the "weight" (the amount of ink the type puts on the paper), closing of holes, openings in solid lines, and spaces where lines intersect are but a few. Vertical or horizontal displacement of the character as well as slight rotation would be classified as distortion. This study is concerned with four simulations of distortion. Random unbiased distortion consists of randomly selecting quantized cells of a character and changing them. This includes the background (to supply "noise") as well as the image itself. Random biased distortion randomly deletes a row or column of the quantized characters until the desired distortion is established. Numerical definitions with a more elaborate discussion of these categories will be given in succeeding sections of this report. The other two simulations are concerned with linear displacement and rotation.

Since the purpose of this study is to provide a means of testing out recognition devices, it is desirable to have at least a broad understanding of character (or pattern) recognition.

Pattern recognition has been defined¹ as the assignment of a meaningful code to a recognizable structure. In practice, the structure is represented by a set of signals. The signals are the result of a transformation (i. e., quantization) of the original pattern. There are many varied solutions to the problem of pattern recognition, of which several may be acceptable. The best, of course, is dependent upon the intended application. In most methods, some form of quantizing takes place. Commonly, quantizing is a process whereby the original pattern is superimposed on a grid and thereby divided up into an array of cells. A binary representation of the pattern is now made possible by assigning a "one" to each of the cells in which a portion of the figure, above some threshold value, occurs, and a "zero" to each blank cell (i. e., no part of the figure or an amount less than the threshold occurs). In some cases the threshold is kept as a parameter. There are roughly three

categories of recognition systems. A brief description of these categories is as follows.

The first is the element matching system in which selected cells (peephole matching) or the entire array of cells of the unknown character are matched with corresponding cells of known characters. The matching can be done logically or statistically, one at a time or in parallel.

Secondly, there is wave-shape comparison. Using optical or magnetic transducers, a wave shape characteristic of the scanned unknown character is obtained and compared with a set of wave shapes of known characters. The character whose wave shape provides the greatest correlation is chosen. Threshold values are used to prevent inaccurate identification by causing rejection of characters which provide excessively low maximum correlation coefficients.

The third method incorporates a form of characteristic extraction. This method is based on the assumption that certain features may be found which are invariant under slight distortion. In many characteristic extraction methods, a decision-tree is used.²

It is the object of the recognition system to utilize the output of the scanner (or any transformation unit between source and input) and through a series of transformations or operations on these data, identify the original pattern. The output of this system would be a code emblematical of the unknown character.

2. THEORETICAL BASIS

Ideally, for testing character-recognition devices, a statistically significant set of samples representing all of the conceivable inputs should be available. These samples should represent errors produced in the original typing or printing, errors in the centering of the image, errors produced by the scanner, etc. Several routines have been developed, the use of which (separately or in various combinations) attempts to adequately simulate many of the conditions described above. To facilitate the simulation of these conditions as well as to allow for greater flexibility, the percentage of distortion

and the resolution are treated as parameters. Also arbitrary is the use of Binary or BCD inputs and outputs.

An ideal set of characters was quantized with scanning assumed to be vertical starting at the upper left of the character. The digital representation resulting from the quantizing is then placed on IBM cards with each card taking one scan. Initial positions on the card were used to designate the character. For instance, columns were used to identify whether the character was alphabetic, numerical, symbolic, or punctuation, what the origin set was, and which image of the set is partially contained on the card. A final column was used to denote the sample number. One sample consists of a complete set of characters from the alpha-numeric set in question. The number of samples tells the routines how many total characters will be read in, thus enabling the computer to test for the last sample. Columns were also used to denote the scan number. The rest of the card is available for the scan.

Percentage random unbiased distortion is defined as the ratio of the number of cells changed to the number of cells scanned. Formally, for a 30 x 32 resolution where 15 percent random unbiased distortion is desired:

$$0.15 = \frac{X}{(30)(32)}$$

X equals 144 which means that 144 cells will be selected at random and their contents changed. Fractions are truncated. It is obvious, therefore, that to achieve the distortion of individual cells or bits of the quantized character, we must be able to address them individually. The data cards representing the resolutions of the individual characters are read into the computer according to a format which causes the resolution to be treated as a double subscripted variable. This allows each cell to be stored in the computer as a separate word. To change a bit, we merely have to "call in" the word and test its contents, and set it equal to the opposite condition.

The arbitrary parameters are read in to determine resolution dimensions, percentage distortion, number of samples, output tapes, and mode of output (binary or BCD). If binary output is used, it may be desirable to get a listing of one sample to be assured that the results are as intended. The parameters

are read in, the characters stored, and the number of cells to be changed is computed. Loops are set up to provide the desired quantity of output and the distortion is performed. Two random numbers are "called in" (magnitude between 0 and 1) and each is multiplied by a resolution dimension. The two resulting numbers can then be used as subscripts to call in the cell to be changed. Since the characters are made up of 0's and 9's (representing absence and presence of the original image, respectively), a test is made to determine whether the cell contains a 0 or a 9 and the cell is changed accordingly. The choice of 0's and 9's was arbitrary. The output is then recorded and the program continues to completion.

This routine is an attempt to simulate the random distortion which might be caused by an inefficient scanner, filter, or smoother. (A filtering unit and a smoothing unit are two devices which, in practical applications, might precede the recognition device and filter out extraneous noise and smooth over straight lines and curved sections.)

The displacement routine performs random shifting. The input parameters are resolution size, number of samples, input and output tape unit numbers, binary or BCD model control, and maximum linear shift. This routine performs four shifts, one in each direction of a random number of cells (less than an arbitrary maximum). The resulting image has been shifted, at least partially, into one of the four quadrants. The empty cells have been left blank. This routine is an attempt to simulate conditions which may be caused if the printer or scanner is off center.

One of the most important requirements of these distortion subroutines is that they adequately simulate the conditions which may be imposed by inefficient or inadequate devices which would precede the character recognition system. This must be accomplished with no knowledge as to what the original image was, where it was, or, in some cases, what form of type was used in its printing. The most probable source of distortion is the worn typewriter ribbon. The random biased distortion routine attempts to simulate this condition.

Referring to figure 1, we can see that if a section of a typewriter ribbon has been used consistently to type such characters as P, H, t, A, B, R, E,

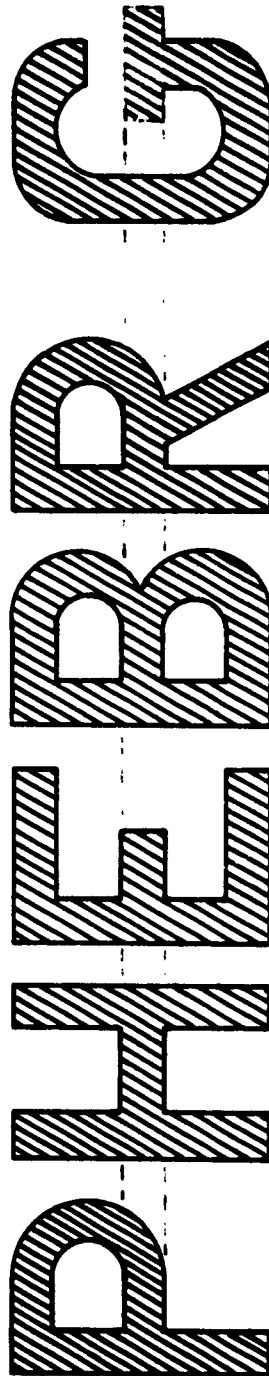


Figure 1

F, and 1, the central part of the ribbon could conceivably become worn and produce a G which resembled a C as is shown. Such an example may be extreme; however it serves to demonstrate the objectives of this routine. The routine randomly selects and deletes entire rows and columns of the quantized character. To accomplish this, a random number is used to select between row deletion and column deletion. A second random number chooses the row (or column) to be deleted. If we define percentage random biased distortion in a similar manner as we did unbiased distortion, then for a 30 x 32 quantization, with 25 percent random biased distortion:

$$0.25 = \frac{x}{30 + 32}$$

$$x = 15.5$$

With a total of 62 rows and columns, (0.25) (62), or 15 deletions must be made for 25 percent random biased distortion (fractions are again truncated). The deletions are accomplished in the IBM 7090 by equating each element in the selected row (or column) of the character to zero (which represents absence of image).

The definitions of the two types of random distortion are independent of the type style as well as of initial quality. For a given resolution and a fixed amount of distortion or deterioration, lower case letters and capital letters are affected in accordance with the respective space covered by each. To demonstrate this advantage, let us assume that we have a bit counter following the scanner and define percentage random unbiased distortion as the ratio of cells changed to the total number of 1's produced (assuming that the quantization process consisted of 1's and 0's). This causes distortion to become a function of the size of the image rather than of the size of the area scanned and the resolution. If we have high resolution (a large number of cells per unit character area) and a small original image, we could, by this new definition, achieve 100 percent deterioration and not change a single cell of the original image. It is also noteworthy that we could not distort a space with this definition... a procedure which is desirable for testing threshold values. It is necessary that distortion be defined as a function of resolution

size with no dependence upon l's count or size of the scanned image.

An attempt was made in this study to provide a program which would rotate the character a random number of degrees. The brute force method of accomplishing this would be to sketch out on paper an actual rotation for each degree (clockwise as well as counterclockwise) and have the result programmed for each case. This would require an instruction per cell, per degree. Such a procedure would mean a program of approximately 50,000 instructions for a 50 x 50 quantization ($50 \times 50 = 2500$ instructions per degree, 25,000 for a maximum of only 10 degrees in one direction, and 50,000 for a maximum of 10 degrees in both directions). This method was discarded for obvious reasons.

It must be realized that, to be practical, a rotation routine should be compatible with the other routines developed with this study. We therefore must start and end with the rectangular type of representation of the characters. Each character, before being shifted, possesses a certain information content. Unless the character is shifted much beyond the confines of the quantization, the information content will remain approximately the same. In circular shifting (or rotation) cells are moved in directions not normal to one of their sides. Some cells will therefore not fall completely into a new cell (as in linear shifting) and the information content of the character will consequently be diminished. To preserve the information content of the characters, a circular representation was established which provides for each cell.

It is noted that in the previously discussed shift, the character was treated as having rectangular coordinates, and only one coordinate was changed in performing the shift. An attempt was made, for rotation, to transform the rectangular representation to a circular representation and similarly change only one coordinate (the "angle"), and then transform back to the rectangular representation. A 50 x 50 quantization was selected and rotation was performed about the midpoint. The original quantized character (being, in most cases, smaller than 50 x 50) can be placed in any part of the 50 x 50 mesh and thereby rotated about points other than the center. The changing of coordinate systems was accomplished by setting up "vectors" from the center. The quantization was viewed as being a sequence of concentric squares. The first "circle of squares" contained 4 squares numbered consecutively starting at the upper

left corner. This procedure was continued through vector 25, which contained 196 squares. When the rotation angle was selected, the squares of each vector were rotated (i. e., clockwise) according to the formula:

$$(Y) \left(\frac{x}{360} \right) = \text{number of squares shifted in particular vector}$$

where Y is the number of squares in the vector in question and x is the number of degrees of rotation. The parameters available in the various sections of the routine provide for (1) the optional print-out of the character location in the 50 x 50 matrix (in case center rotation is not desired), (2) card or tape input, (3) binary or BCD input, (4) a controlled or random amount of rotation, (5) controlled or random direction of rotation, (6) choice of maximum rotation, (7) optional print-out of results, and (8) binary or BCD output.

Unfortunately, this program provides more than was originally intended. While working perfectly for angles of 0, 90, 180, 270, and 360 degrees (in either direction), it produced distortion at angles between these. It is possible that this program, in its present form, may be useful for generating samples to test cursive handwriting. While this would be for handwritten character recognition, an undistorted rotation is still desirable for printed images. Work is continuing in an effort to develop an acceptable code for "pure" rotation. One possible approach which is being considered is that of viewing the quantized character as a mapping, and developing a transformation "multiplier" which would rotate the character as desired.

3. EXPERIMENTAL RESULTS

Before demonstrating the application of the distorted characters, it is first necessary to briefly discuss the particular character-recognition program used. The basic program was written by Breuer³ and recognition is based upon probabilistic comparisons. A set of "known" characters is used to establish frequency distributions of element values. Each cell is assumed to be independent of other cells; however, the probability of a given character's occurring becomes either less or greater with the knowledge of the contents of each new cell examined. A probability matrix is thereby set up for each character in the set.

As each unknown is introduced to the program, it is possible, on a cell-by-cell basis, to compute its "score-of-match" with respect to each character of the set. A "best-fit" is used for decision making in this particular program; however, a threshold could be incorporated if desired.

To demonstrate the application of the distorted characters, this report will discuss only the recognition test in which the random unbiased distortion characters were used. Since these programs are completely compatible with each other, the usage is identical for all routines.* A set of ten similar characters was used. A sample "perfect" character is shown in figure 2. A discussion of some of the tests run and their results follows.

a. Random unbiased distortion -- 3 percent

The 3-percent figure was chosen as a low value which would provide sufficient distortion to test a recognition routine yet not enough to exceed the recognition efficiency of the routine. A sample with 3 percent distort is shown in figure 3. The figure is outlined, as are the individual cells whose contents have been changed. In a 30 x 32 quantization, 3 percent random unbiased distortion will alter 28 cells.

b. Recognition -- unbiased distortion

An ideal character-recognition scheme would be capable of the correct identification of a pattern as long as it is recognizable by the human eye. This, of course, is a grossly unrealistic goal, because of the innate ability of the human being to include prior context and concurrent stimuli along with visual acuity. Also, when a pattern is distorted beyond human recognition we would like the ideal scheme to "reject" the pattern as non-recognizable. The ability of the character recognition scheme to correctly identify a pattern should therefore parallel, as close as possible, that of a human being.

It can be seen from figure 3 that patterns with 3 percent random

*A listing of any of the programs is available from the author.


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Figure 2

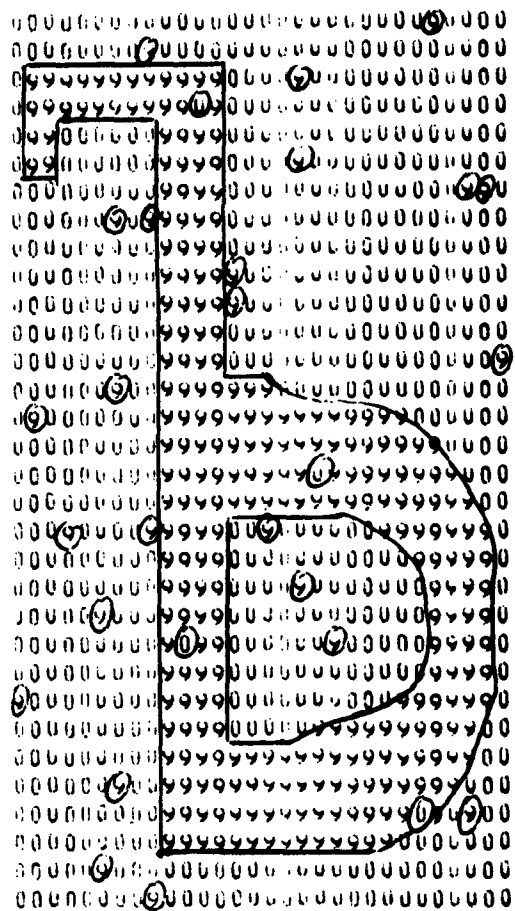


Figure 3

unbiased distortion are still easily recognizable. We therefore should expect that a character recognition routine would have 100 percent efficiency when attempting to recognize these characters. When these characters were examined by the recognition routine, correct recognition was achieved in each case by a considerable margin. At this low level of distortion the recognition routine produced the desired results.

Recognition of patterns with up to 20 percent random unbiased distortion was also 100 percent effective. The theoretical goal of a recognition program, as pointed out previously, is to accurately identify patterns with 100 percent efficiency until distortion is increased to the point where such efficiency by a human being is impossible. It is interesting to note that while the character shown in figure 4 with 20 percent random unbiased distortion, is recognizable to a human being, (only after a few seconds of concentration before outlining), the routine was able to effect correct identification by a considerable margin.

While 20 percent is probably above the maximum amount of distortion of this type that would be encountered in a practical situation, this author was curious to see if the crossover point from 100 percent efficiency to something less would be the same for both the routine and the human being. Figure 5 shows a picture of a character distorted with 30 percent random unbiased distortion. As the reader will note, recognition by a human being is possible only after close study of the character (again, before outlining). It is reasonable to assume that the crossover point for the human being would be passed with a slight increase in distortion. While 100 percent effectiveness did occur with these characters, the margin of correct choice was quite small. The effectiveness of this recognition scheme in handling this particular type of distortion is clearly indicated in this brief experiment.

c. Random shifting — 3 percent distorted characters

The random shift routine shifts the pattern a maximum of six cells in each of the four directions (up, down, left, and right). Six was arbitrarily selected as providing an adequate shift for testing out the recognition routine with a modification for centering. Figure 6 shows the results of the random

Figure 6 .

shifting. The characters used were the 3 percent distorted characters from the previous experiments.

d. Recognition -- shifted characters

When the shifted characters were presented to the recognition routine, an efficiency of approximately 72 percent was achieved. It should be pointed out that in this experiment an attempt was made to recenter the known character before undertaking recognition of the unknown. The unknown characters in this experiment were not recentered. An improvement in efficiency could possibly be effected by recentering of both known and unknown characters; however, such tests have yet to be performed.

e. Random biased distortion/recognition

Figure 7 shows a character which has received 20 percent random biased distortion. With a 30 x 32 quantization this results in the deletion of 12 rows and/or columns. While relatively large sections of the character were deleted in some cases, recognition is still an easy matter if done visually. When the recognition routine was used, the effectiveness was 100 percent.

f. Rotation

To show rotation, the Cyrillic letter \ddot{E} was chosen because of the two dots at the top of the letter. Looking at the four rotations shown in figure 8, one can possibly use the positions of the dots to better visualize the amount of rotation imposed upon the main body of the original image. The figure shows 5 degrees counterclockwise, 15 degrees clockwise, 45 degrees counterclockwise, and 90 degrees clockwise, respectively. The distortion mentioned in the discussion of this program becomes highly evident for angles of rotation in excess of about 10 degrees. As this method views the quantization as a sequence of concentric squares, the rotation performed is actually a combination of vertical and horizontal shifting of the cells. Since circles have no edges or sides such a procedure is bound to cause distortion.

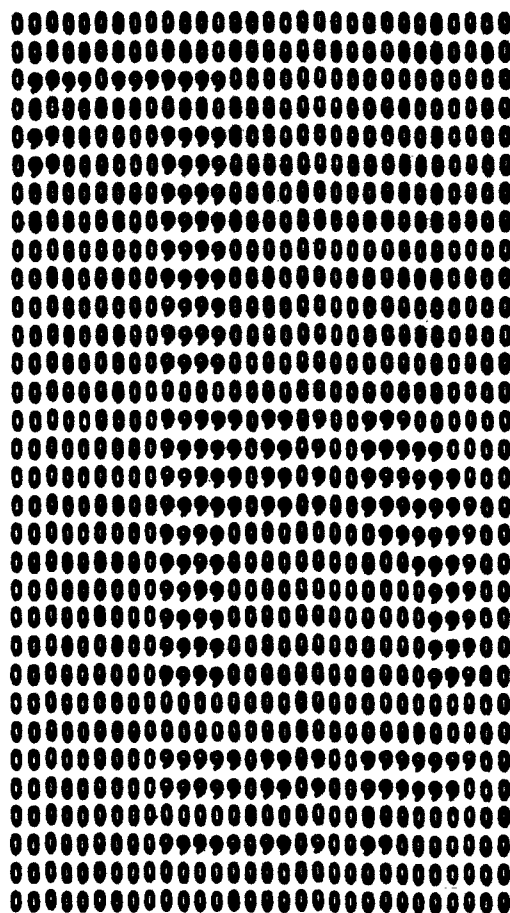


Figure 7

4. CONCLUSION

The real test of a character recognition device begins when it must identify not only ideal figures but also disturbed figures as they will occur in practical application. The need for programs to produce "artificial" characters is apparent. It is hoped that the programs developed in the course of this study will help to alleviate this need.

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